



Frontiers: Current Challenges in Food Process Design and Engineering

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INTRODUCTION

For thousands of years humans have been involved in the production of food using different processing and preservation methods. Archaeological evidences have been supportive of the fact that early civilizations were using different processing techniques to preserve food and hence increase its availability and sustainability for the growth of civilizations. Drying, smoking, heating, salting, freezing, fermentation and pickling have been some of the key traditional processes used for transformation and preservation of food.

Food processing on industrial scale really kicked off in 19th century for making food available for large population by introducing preservation principles of pasteurization and sterilization in food processing. Rapid industrialization in 20th century that resulted in fast pace life has withdrawn the time for home cooking catalyzing a demand for ready-to-eat type of meals. Reliability on packaged ready-to-eat type of meals has forced manufacturers and governmental regulators to make sure that produced food is wholesome in nature and would suffice nutritional and safety requirements from that specific food.

From ancient to present time processing techniques used for production and distribution of food on a broad industrial scale have been associated with five concepts:

- 1) Application of physical (mechanical) energy to reduce, enlarge, separate, homogenize, or otherwise change the physical form of solid, semi-solid, and liquid food matter
- 2) Application of thermal energy to elevate temperatures to cook raw products and to achieve long term or extended stability or preservation
- 3) Removal of thermal energy to reduce product temperature and extend shelf-life during storage
- 4) Removal of water from products structure and thus achieving of extended shelf-life
- 5) Recovering valuable soluble components from raw materials

The rapid urbanization of the world has created new challenges for the modern food industry. Trends for more frequent food consumption outside the home and fast preparation of ready-to-eat meals has led to growing numbers of produced foods and ingredients. Consequently, this has resulted in the growing industrialization of food production, globalization and trade of food supply and a growing number of food recalls. The industrialized production of foods has to guarantee retailers and consumers enhanced food safety and nutritional quality of locally grown products. In addition, it must satisfy consumer desires of additional health benefits as well as retailers demands for longer shelf-lives.

Minimal processing without added chemical preservatives started to emerge into food production to increase productivity and provide safety and quality through shelf-life of foods. The advantages of new advanced minimal processing methods are that they are not affecting quality, nutritional, and organoleptic attributes and taste more like fresh products. Over the last 2 decades, the sixth

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processing concept often called Novel Processing has been emerging globally in food production. Novel Food Processing Technologies have been advanced not only for better transformation and preservation purposes but also as new tools to tailor foods with added or enhanced functional and nutritional values. In many countries' food products produced via novel processing techniques are considered as Novel Foods and often can replace conventional style foods. For example, old style ham treated by high pressure or fresh apple cider pasteurized using ultraviolet light for better product safety become Novel Foods.

Additionally, novel processing technologies have potential to reduce effects of thermal abuse on foods, to lower carbon footprint and substantially reduce water volumes used in heat transfer processes.

This sixth novel processing concept includes advanced thermal, mild and nonthermal processing technologies based on utilization of:

- 1) Mechanical Energy
 - a) Pressure (hydrostatic and hydrodynamic)
 - b) Ultrasonication
 - c) Ultrafiltration
- 2) Electrical and Electromagnetic Energy
 - a) Irradiation (gamma, x-rays and electron beams)
 - b) Light (ultraviolet, blue, visible, infrared, pulsed)
 - c) Microwave and Radio Frequency heating
 - d) Ohmic and Conduction heating
 - e) Pulsed electric fields
 - f) Cold plasma
- 3) Chemical Oxidation
 - a) Ozone
 - b) Advanced oxidation
 - c) Super critical carbon dioxide
- 4) Combined Applications

EMERGING TECHNOLOGIES

Frontiers of scientific discovery and technological innovations will continue to expand and replace those existing processing approaches and technologies. Among these recent innovations are applications of 3D food printing to create personalized diets and foods. Furthermore, future long term space missions will require innovations in food production and processing without gravitational forces, using alternative sources in the limited space and provide high nutritional meals.

This paper presents and discusses current and future challenges, knowledge gaps for each of the above-mentioned concepts of modern Food Processing and Engineering with a focus on food industry needs, conventional industrial practices and traditional and ethnic foods, novel and emerging technologies and operations.

Grand Challenge #1—Food Industry

The main challenge modern world is facing and would always be a growth in human population, overpopulation and heavy

urbanization. Food industry consumes a relevant quantity of energy and potable water, and the pressure to reduce is still beginning. Moreover, a significant part of energy is based on nonrenewable sources such as petroleum derivatives burned to produce steam. Consequently, moving processes towards less energy consumption and renewable sources is needed. This triggers pressure on food industry to meet the constantly growing production needs but with emphasis on reduction of waste, energy and water. Therefore.

- Food industry has to meet needs of feeding the constantly growing and aging world population via improvement of conventional processing technologies, development and commercialization of novel and emerging technologies, and development of personalized foods with optimized nutritional requirements for different groups of people and enhanced nutrients availability.
- We should know more about:
 - How foods interact with human body. How food processing(s) affect on these phenomena.
 - Advancing processing methods with emphasis on reduction of raw materials, food by-products, food products waste, energy, water and other resources.
 - Development of processing approaches to produce high quality alternatives to animal proteins, including non-conventional plant sources and consumption of insects
 - Concepts of circular economy, bioeconomy and biorefinery force food industry to extract all the possibilities of each raw material. The current residues have to be gradually extracted and converted into by-products, co-products and finished products.
 - Impact of climate change on natural microflora and properties of crops and raw materials and consequently processing, stabilization and storage methods from farm to the table.

Grand Challenge #2—Mechanical Process Operations and Food Structures

To facilitate further advancement of the mechanical processing of food materials in order to create the best state for processing and adjust properties of food materials to increase the effectiveness of heat and mass transfer operations, improve quality, edibility and digestibility of raw and prepared foods, allow for a greater range of food products to be made, and reduce waste and energy consumption, To develop and make tailor designed foods through connection of composition, structure and processing.

Grand Challenge #3—Thermal Processing and Cooling Operations

Since introducing transformation and preservation principles by using heat in food processing in the 19 century, food industry along with scientific community accumulated critical knowledge for establishment of thermal and other conventional processes that included:

- Established organism of public health concern
- Well understood and known kinetics of microbial destruction mainly based on a first order reaction
- Knowledge of products heating in given processing systems
- Establishing of equivalent safety and comparison of different processing systems expressed in “Lethality” terms.

Despite of this existing knowledge accumulated during more than 200 years of development, there are still gaps in knowledge and challenges that need to be addressed.

- Further improving efficiency of energy conversion, better utilization of heating medium and higher process yield
- Alternative energy sources and methods for heating, drying and cooling
- Development of integrated knowledge about food stability that includes microbiological, chemical, physical and biochemical aspects
- Advance knowledge of microbial and enzyme inactivation kinetics, as well as physical–chemical reactions in food products.
- Developing of multifactorial and multidisciplinary models, data and properties that are necessary to achieve optimized processes and products.
- Alternative more economical and effective extraction and conversion methods with improved yield

Grand Challenge #4—Novel Processing Technologies

This technological development is still relatively new and still in a phase that needs a substantial amount of research, validation and commercialization efforts to prove its pragmatic feasibility.

Due to different fundamental principles of novel technologies, performance capabilities of novel processes differ from conventional processing in terms of the types of food categories that can be treated, microbial and enzyme inactivation efficacy, destruction models and mechanisms, desired and undesired effects on food quality, and their economic and environmental impact. The next essential steps in developing novel technologies are:

- Evaluation of equivalency of conventional, advanced thermal, mild thermal and nonthermal processing methods
- Further development of principles and approaches of novel process validation, verification and control methods
- Investigate opportunities to use novel technologies as pre-treatment operations to improve yield of process operations, energy efficiency, properties and functionality of food products, reduce waste and water use through recycling.
- Provide solutions of effective combination of processing methods based on knowledge of fundamental mechanisms
- Develop multifactorial models to evaluate process uniformity, delivery and accelerate scale up.
- Applications of novel technologies other than preservation or safety have to be studied to develop high value-added processes or to identify more saving opportunities.

Grand Challenge #5—International Policy

Lack of regulatory approvals has been delaying a wider implementation of novel technologies in the industrial scale. Before a novel or emerging process can be used and product can be sold the thorough reviews of impact on quality and nutrition, and evaluations of safety of novel process and consequently novel foods have to be conducted by food industry professionals and regulatory agencies. As a result, the incremental developments of novel technologies for a variety of food applications led to significant accumulation of new scientific and engineering information and science-based regulations.

- More information is required to demonstrate effects on nutritional, allergenicity and toxicological profiles and possibility of formation of undesired compounds to accelerate regulatory and consumers acceptance.
- To explore ways to better use existing knowledge and fill gaps to develop harmonized regulations and translate them into practice.

Grand Challenge #6—Emerging technologies

- Advancing emerging processing strategies such as 3D printing to facilitate development of personalized meals and diets by controlling properties, composition, structure, shape and color.
- Developing new fundamental principles and practical approaches in food production and process engineering that will be necessary when considering long-term space mission

Grand Challenge #7—Processing of Ethnic and Traditional Foods

Historically traditional and ethnic foods have been documented for more than 5,000 years. They have been produced wisely from locally available, accessible and affordable raw materials in various seasons. Some interesting topics to be covered are:

- The importance of process design to provide low cost, nutritious, pleasant, sustainable and secure traditional and ethnic product or food ingredients.
- Translate wisely practices used to produce traditional and ethnic foods to science based technological methods.
- Authenticity and identity of traditional and ethnic foods as affected by various food design and processes.
- The advancement of food design and process of traditional and ethnic foods over time into commercial production.
- The combination of food design and process of traditional and ethnic foods and conventional, emerging, and novel food design and process (ing) methods to:
 - Tackle current global challenges in food sector particularly in developing countries to address food shortage as well as food and nutrition insecurity.
 - Respond new, emerging, and challenging food issues such as producing emergency/disaster and space foods. For

instance, some space foods vitally should be shelf/self-stable with low volume and mass.

FINAL REMARKS

The goal of the new specialty section, “Food Process Design and Engineering” is to assist in addressing critical issues in processing conventional foods, ethnic foods, novel foods and future personalized and space foods through further advancement of existing and emerging technologies and sources. It will bring opportunities as a new knowledge platform for food researchers, scientists, engineers, professionals, technologists and policy makers in food industry in developed and developing worlds. We wish to embrace open access knowledge for all professionals and assure true transparency and equality in publication, to accelerate constructive knowledge exchange and discussions between industry, academia, innovation strategists and policy makers through the open access publications.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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